

## **Range-Dependent Acoustic Propagation in Shallow Water with Elastic Bottom Effects**

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### **LONG-TERM GOALS**

The long-range objectives of this research are to develop efficient accurate tools for quantitative forward modeling in range dependent, bottom-interacting acoustic propagation including sediment anisotropy and anelasticity.

### **OBJECTIVES**

The specific objectives of this research are to develop practical theoretical and software tools for employing a fully elastic version of two-way coupled modes for modeling seismo-acoustic signals in shallow water with realistic elastic bottom properties, that may extend to elastically anisotropic sediment cover.

### **APPROACH**

The Call for Planning Letters suggested interest in acoustic frequencies as low as 10 Hz. This frequency corresponds to a wavelength of 200 m for a sediment compressional speed of, say, 2000m/s. At such low frequencies acoustic penetration into sediments is significant. Elastic effects (shear) cannot be ignored. In addition ocean sediments are often elastically anisotropic by the very mechanisms by which they are formed. If the anisotropy is significant, horizontally polarized shear waves (SH) can be generated even from an explosion source in the water. This conversion to SH is required by the boundary condition at the interface between the water and sediments at the ocean bottom. The attenuation in near bottom ocean sediments may be very high. It may be high enough that perturbation theory is inadequate for properly describing loss in shallow water acoustic propagation. Finally there is range dependence, which can be significant in littoral regions. This project addresses two of these shallow water issues.

*Range Dependence:* As mentioned above, range dependence can be quite significant in littoral regions. There are currently available excellent codes for computing bottom interacting acoustic signals in shallow water for 1-D. Henrik Schmidt's OASES program, a direct descendent of the original SAFARI, has solved the 1-D problem for isotropic elastic bottoms. OASES is efficient, can accept

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arbitrary layered bottoms, and, very importantly, is numerically utterly stable. The currently available version is 1-D. 2-D models do exist. William Siegmund and colleagues have produced a very fine parabolic equation model for propagation in range dependent media and even includes transverse isotropy. I and my past students (see References) have derived and coded a range dependent elastic model based on coupled modes. This incorporates arbitrary range dependence, and includes both forward and backwards propagation. The backwards propagation is not an approximation, a point it is important to emphasize. We generate the set of local modes, and solve a matrix Riccati equation over the range dependent section to arrive at the forward and backwards propagating fields. Currently the code must be run in a very hands-on batch mode. We are converting our current very hands-on code into a more generally useful tool. We are also working closely with both Scott Frank of Marist College, and Jon Collis of the Colorado School of Mines, who are former Ph.D. students of Siegmund's and experts in the elastic PE.

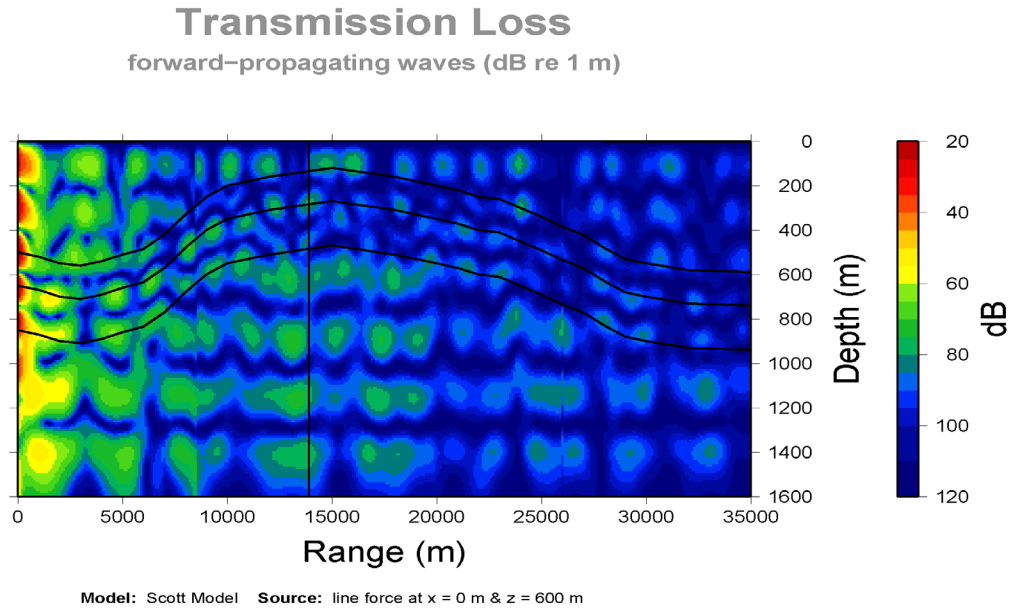
*Anisotropy:* Our local mode model incorporates anisotropy with hexagonal anisotropy, but an arbitrary symmetry axis. By incorporating this into a time domain range dependent code we will be able to trade off the effects of range dependence and anisotropy in the modeling. Much of the trade-off work has been done locally, and has been submitted to JASA. However we have not incorporated this into the time domain propagation results. This is planned for the future.

## **WORK COMPLETED**

This project was a new-start for FY11. Since then we have submitted two papers to JASA, both in review, and a Conference Paper. We have submitted two papers on the anisotropy trade-offs to JASA (Soukup, Odom, and Park, 2011 and 2012). Last year, working with both Scott Frank and Jon Collis, we agreed on a common range dependent environmental model to employ with both the coupled mode and PE computations. We have implemented that model for our coupled-mode computations and just begin comparisons with the elastic PE model. Our coupled-mode code development and execution was carried out by Dr. Minkyu Park of the Korean Polar Research Institute(KOPRI) in Incheon, Korea. Dr. Park has been on sabbatical for almost two years as a Visiting Scientist at the Applied Physics Laboratory, University of Washington (APL-UW).

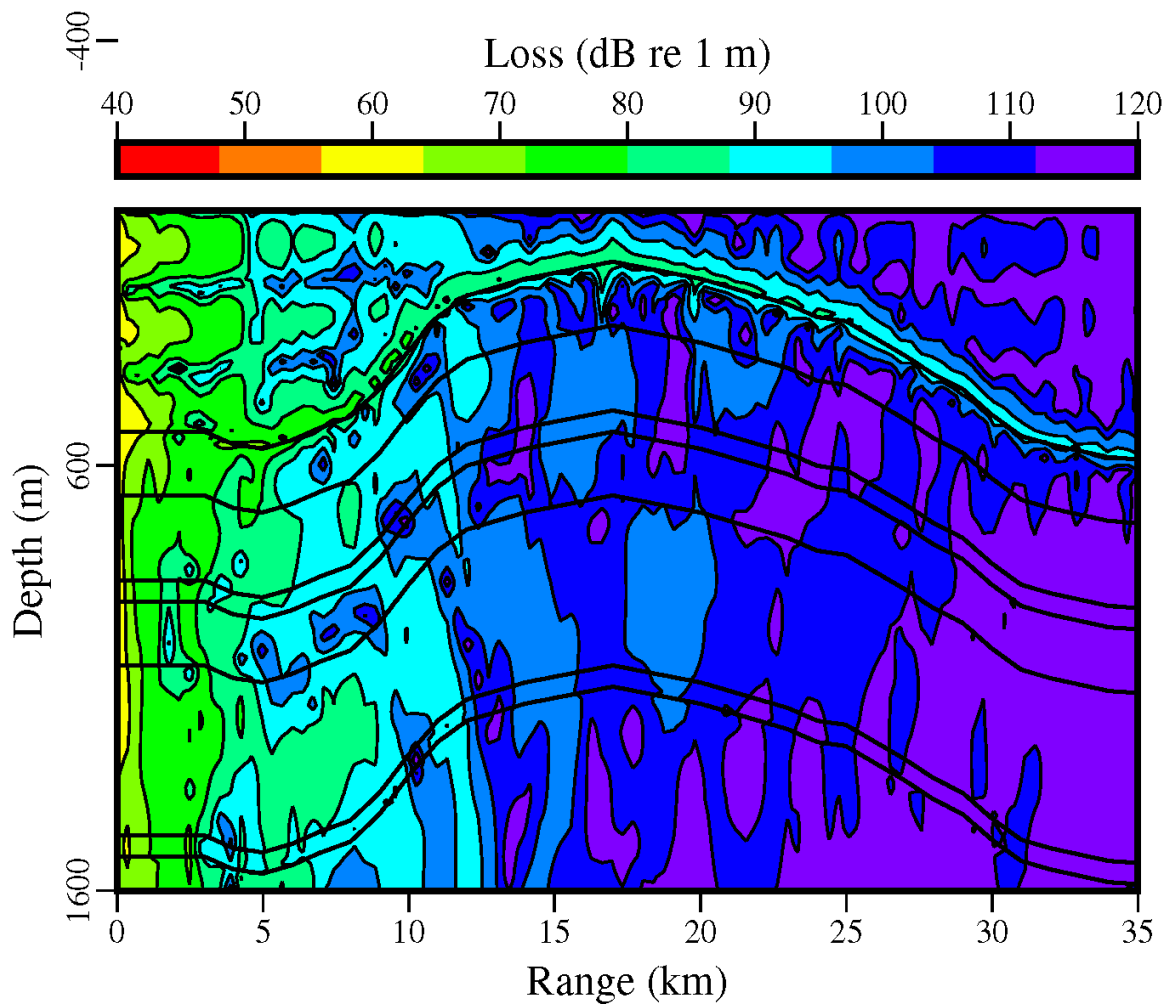
## **RESULTS**

Figure 1. is transmission loss (TL) for a range-dependent fluid-elastic model, incorporating a 1500m/s ocean layer, a 150 m layer of sediments with compressional velocity of 2400m/s, shear velocity of 1200m/s. A faster layer with compressional speed and shear speed of 3400m/s and 1700m/s, respectively, and terminated by a fast basement with a compressional and shear speed of 5000m/s and 2887m/s, respectively. The range-dependence models a seamount of approximately 400m in height and about 20km in range extent. The seamount is 2-dimensional. The plot is preliminary, but among other things, shows clear interface (Scholte/Stoneley) waves guided along the boundaries at shorter ranges. We are also able to compute backscattered loss, as a natural byproduct of the two-way coupled mode computations. For this model, there is essentially no backscattered energy, as we do not include a figure.



***Figure 1. Transmission loss (TL) for a range-dependent fluid-elastic model, incorporating a 1500m/s ocean layer, a 150 m layer of sediments with compressional velocity of 2400m/s, shear velocity of 1200m/s. A faster layer with compressional speed and shear speed of 3400m/s and 1700m/s, respectively, and terminated by a fast basement with a compressional and shear speed of 5000m/s and 2887m/s, respectively. The range-dependence models a seamount of approximately 400m in height and about 20km in range extent. The seamount is 2-dimensional. The plot is preliminary, but among other things, shows clear interface (Scholte/Stoneley) waves guided along the boundaries at shorter ranges.***

Figure 2. shows a TL result computed by Scott Frank (Marist College) using the elastic parabolic equation (PE). There is a strong interface wave visible. One of the main goals of the project is a comparison of the elastic coupled modes with the elastic PE. These comparisons have just begun, as our coupled mode results are quite recent.



**Figure 2.** *A TL result computed by Scott Frank (Marist College) using the elastic parabolic equation (PE). There is a strong interface wave visible. One of the main goals of the project is a comparison of the elastic coupled modes with the elastic PE.*

The main feature of both Figures 1. and 2. Is the presence of the interface waves, which do not exist in a purely fluid model. The interface waves are strictly an elastic, and will not be seen in a fluid-only model.

## IMPACT/APPLICATIONS

This work will lead to a practical method to investigate seismo-acoustic propagation in shallow-water environments, and allow us to compare and contrast various environmental effects on the seismo-acoustic wave-field.

## RELATED PROJECTS

Our research is directly related to other programs studying effects of propagation at low frequency bottom-interacting sound.

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